Simulation Chamber for Space Environment Survivability Testing

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Simulation Chamber for Space Environment Survivability Testing

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Abstract

A vacuum chamber was designed and built that simulates the space environment making possible the testing of material modification due to exposure of solar radiation. Critical environmental components required include an ultra high vacuum (10-9 Torr), a UV/Vis/NIR solar spectrum source, an electron gun and charge plasma, temperature extremes, and long exposure duration. To simulate the solar spectrum, a solar simulator was attached to the chamber with a range of 200nm to 2000nm. The exposure time can be accelerated by scaling the solar intensity up to four suns. A Krypton lamp imitates the 120 nm ultraviolet hydrogen Lyman alpha emission not produced by the solar simulator. A temperature range from 100K to 450K is achieved using an attached cryogenic reservoir and resistance heaters. An electron flood gun (mono-energetic, 20 eV to 15keV) is calibrated to replicate solar wind at desired distances from the sun. The chamber maintains 90% uniformity of the electron and electromagnetic radiation exposure relative to the center. The chamber allows for a cost-effective investigation of multiple small-scale samples. An automated data acquisition system monitors and records the reflectivity, absorptivity, and emissivity of the samples throughout the test. An integrating sphere and an IR absorptivity/emissivity probe are used to collect this data. The system allows for measurements to be taken while the samples are still under vacuum and exposed to radiation. With these accurate simulations we can closely predict the material's behavior in near proximity to the sun. This information is vital in determining materials for satellites, probes, and any other spacecraft.

Experimental Test Chamber Design

In Situ Analysis Capability

UV/Vis/NIR Reflectivity Two fiber optic spectrometers (F) measure reflectivity. UV/Vis/NIR (200-1000 nm) NIR (850-1700 nm) ranges with <1 nm resolution. Integrating Sphere-A 2.5 cm diameter integrating sphere (H) can be extended over the samples with a retractable probe. Linear translation stage (T). The sample stage can be rotated to position different samples under the probes. Light from a deuterium/halogen calibrated light source enters the integrating sphere through one fiber optic connection; reflected light from the sample exits through another fiber optic to spectrometers. IR Emissivity-Measured with retractable probe (4 μm to 15 μm) coupled on probe translation stage. Calibration Sample(s) in high and low reflectivity/emissivity calibration standards (N) are mounted behind the probe translation stage. Light Flux-Continuously monitored with in situ photodiodes (I) and equipped with Head-end Air Mass Zero (M) filter. Monitored with pyrheliometer, pyranometer, and Standard Air Mass Zero filters (D) to match the incident radiation spectrum to the monochromator. Sample Stage- Sample stage (M) connected to 35º rotary feedthrough (S) to position samples under probe translation stage (T) and enhance flux uniformity by periodic rotation. Sample stage shown has six 2.5 cm diameter samples (L) plus flux sensors (I, H). Alternate configurations have up to six 10 cm diameter samples. Uniform temperature over ~100 K to 450 K controlled using attached cryogenic reservoir (R) and resistance heaters (F). Large thermal mass helps maintain stable thermal.

Acknowledgements/References


Fig. 1. Chamber Exterior View.
Fig. 2. Chamber Vertical Cutaway View.
Fig. 3. Cutaway View of Beam Trajectories.

Fig. 4. (Right) Sample Level Cutaway View

Fig. 5. (Left) The sample stage can be reconfigured for various sample sizes.

Legend of Components

Sample Carousel
- Sample B. Electron Gun C. FUV Krypton Discharge Lamps D. Air Mass Zero Filter Set E. Flux Mask

Analysis Components
- UV/Vis/NIR Reflectometry System F. IR Emissivity Probe G. Integrating Spheres H. Photodiodes-UV/Vis/NIR Flux Monitor I. Faraday Cup-Electron Flux Monitor J. Platinum Resistance Temperature Probe

Legend of Components

Sample Carousel
- Samples
- Rotating Sample Carousal
- Reflectivity/Emissivity Calib. Standards
- Resistance Heaters
- Cryogenic Reservoir

Instrumentation (Not Shown)
- Data Acquisition System A. Temperature Controller B. Electron Gun Controller C. UV/Vis/NIR Solar Simulator Controller D. Krypton Fluorescence Lamp Controller E. Reflectometry and Reflectivity Light

Chamber Components

Fig. 6. (Top Right) Solar wind and Earth’s magneto-sphere structure.
Fig. 7. (Right) Typical Space Electron Flux Spectra [Larsen].
Fig. 10. (Left) Solar electro-magnetic Spectrum.

Space Simulation Capabilities

Versatile ultrahigh vacuum test chamber provides controlled temperature and vacuum environment with sub-1mbar uniform, long-duration electron and UV/Vis/NIR fluxes at up to 4 times sun equivalent intensities for accelerated testing for a sample area of 8 cm by 8 cm. Particularly well suited for cost-effective tests of multiple small-scale samples over prolonged exposure.

Electron Flux- Electron flood gun (A) provides ≤5·10¹⁶ electrons/cm² (-17PeVcm²) flux needed to simulate the solar wind at more than the 100X cumulative electron flux. Mono-energetic energy range is 0.5 to 15 keV. Gun provides a 99% uniform flux distribution over the full sample area, with "hot swappable" filaments for continued exposure over the entire long duration testing. The electron gun was custom designed at USU after work by Sandia National Labs (2004).

Infrared/Visible/Ultraviolet Flux- A commercial Class AAA solar simulator (B) provides NIR/Vis/UV/UVB electromagnetic radiation from 200 nm to 1700 nm at range covering 4 times sun equivalent intensity for accelerated testing over an area of 8mmX8mm. Source uses a Xe discharge tube, parabolic reflector, collimating lens, and standard Air Mass Zero filters (D) to match the incident radiation spectrum. The solar flux is calibrated to a power meter to match the various accelerations.

Vacuum— Chamber uses standard mechanical and turbomolecular pump (C) for roughing and an ion pump (R) for continuous maintenance-free operation (base pressure <10⁻9 Pa).

Temperature— A temperature range from 100 K to 450 K is maintained to ±25 K by a standard PID temperature controller, using a cryogenic reservoir (C) and resistance heaters (F) attached to a large thermal mass sample stage (F).

Space Environment Characteristics

There are certain characteristics of the space environment that are critical for a true simulation. These critical characteristics are electron flux, electromagnetic radiation, vacuum, and temperature. The electron flux is critical because the solar winds through space bombards spacecraft. The electromagnetic radiation has critical effects on the spacecraft. Light from the sun has a very broad range from the Visual/Infrared to Ultra Violet, specifically the Hydrogen Lyman Alpha emission at 121.6 nm. A vacuum, meaning very few particles. The temperature is critical because it changes drastically depending on proximity to the sun. Things not covered by this chamber are photons/ions, and atomic oxygen.